

Initial Flight Test Results from the EO-1 Advanced Land Imager: Radiometric Performance

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Abstract - The Advanced Land Imager (ALI) is one of three instruments flown on the first Earth Observing mission (EO-1) under NASA's New Millennium Program (NMP). The primary NMP mission objective is to flight-validate advanced technologies that will enable dramatic improvements in performance, cost, mass and schedule for future, Landsat-like, earth remote sensing instruments. ALI contains a number of innovative features, including all the Category 1 technology demonstrations of the EO-1 mission. These include the basic instrument architecture which employs a push-broom data collection mode, a wide field of view optical design, compact multispectral detector arrays, non-cryogenic HgCdTe for the short wave infrared bands, silicon carbide optics and a multi-level solar calibration technique.

The Earth Observing-1 spacecraft was successfully launched on November 21, 2000. During the first sixty days on orbit, several Earth scenes were collected and on-orbit calibration techniques were exercised by the Advanced Land Imager. This paper presents the status of ALI radiometric performance characterization obtained from the data collected during that period.

INTRODUCTION

The Advanced Land Imager (ALI) is a technology demonstration for a possible future Landsat instrument [1,2]. During the first sixty days, data was collected for a series of dark, Earth, Lunar, and Solar observations in order to characterize the performance of the instrument. This paper discusses the instrument functionality on orbit and provides initial verification of the ALI saturation radiance, sensitivity, and signal to noise ratio of each band, based on Earth scene and solar calibration data.

FUNCTIONALITY

The functionality of the Advanced Land Imager includes all aspects of the instrument required to accurately image various Earth scenes: electrical, thermal, commanding, and interfacing with the Wideband Advanced Recorder Processor (WARP) data recorder. Telemetry trending of key instrument voltages and currents indicates the electrical integrity of the instrument has been excellent and well within limits established prior to launch. All temperature sensor readings have been within seven degrees of preflight predictions during normal operating

periods, indicating the thermal performance of the instrument is close to preflight expectations. The observed seven-degree offset can be explained by a warmer instrument pallet caused by additional instrument, data recorder, and X-band phased array usage during the first sixty days. The commanding of the instrument has been nominal with zero errors during the first sixty days on orbit. Finally, no errors associated with the ALI and WARP interface have been identified.

PERFORMANCE ASSESSMENT

Saturation Radiance

The ALI was designed such that the focal plane would not saturate for mid-latitude summer scenes with 100% Earth equivalent albedo. These high saturation radiances will allow for the direct observation of clouds, snowfields, frozen rivers, and glaciers.



Fig. 1: Band 4,3,2 image of Hawaii, HI.

The saturation radiances of the ALI have been checked on orbit by observing scenes with high albedo. Fig. 1 depicts a Band 4,3,2 ALI observation of Hawaii, HI under partially cloudy skies. Fig. 2 depicts a Band 4,3,2 image of East Antarctica. In each observation the high albedo regions are clearly resolved and not saturated. Table 1 lists the maximum radiance and number of counts in each band for each scene.

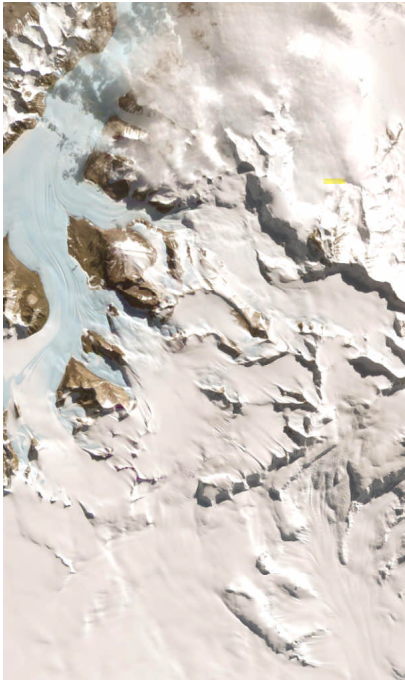


Fig. 2: Band 4,3,2 image of East Antarctica.

TABLE 1
RESPONSE OF ALI TO HIGH ALBEDO SCENES.

| Band | Hawaii HI (Clouds) | | East Antarctica (Ice) | |
|------|--|---------------------|--|---------------------|
| | Radiance (mW/cm ² sr μm) | Counts ¹ | Radiance (mW/cm ² sr μm) | Counts ¹ |
| 1p | 24.52 | 1017 | 15.16 | 619 |
| 1 | 30.44 | 1189 | 18.25 | 705 |
| 2 | 28.36 | 1630 | 15.97 | 939 |
| 3 | 25.03 | 2052 | 13.71 | 1182 |
| 4 | 20.83 | 2705 | 10.68 | 1424 |
| 4p | 17.83 | 2769 | 8.82 | 1423 |
| 5p | 7.92 | 1492 | 1.85 | 342 |
| 5 | 3.43 | 1573 | 0.18 | 82 |
| 7 | 0.76 | 1246 | 0.043 | 72 |
| Pan | 27.67 | 1797 | 15.19 | 980 |

1=Maximum counts = 4095

Sensitivity

The sensitivity of the ALI has been demonstrated by imaging several cities at night. Fig. 3 depicts a panchromatic image of Las Vegas at night on January 22, 2001. Clearly visible are lights from various hotels and casinos. This scene demonstrates the ALI is capable of detecting events with radiances of 0.033 mW/cm² sr μm for this band. Table 2 lists the sensitivities of each band, as determined from this image.

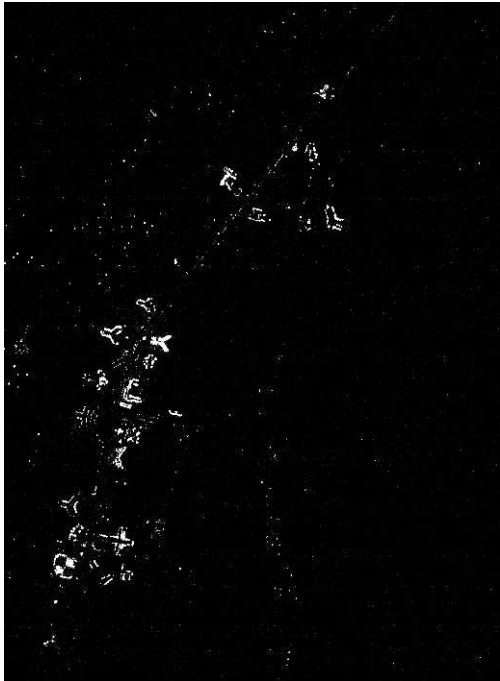


Fig. 3: Panchromatic image of Las Vegas at night.

TABLE 2
ALI SENSITIVITY

| Band | Radiance (mW/cm ² sr μm) |
|------|--|
| 1p | 0.067 |
| 1 | 0.067 |
| 2 | 0.067 |
| 3 | 0.033 |
| 4 | 0.013 |
| 4p | 0.013 |
| 5p | 0.100 |
| 5 | 0.033 |
| 7 | 0.013 |
| Pan | 0.033 |

Signal to Noise Ratio

The focal plane of the ALI has been designed to provide a signal-to-noise ratio for each band between four and ten times that of the Landsat ETM+. To check signal to noise ratios on-orbit, we have selected three regions of a data set,

collected as a part of the on-orbit solar calibration sequence [3], representing low, medium, and high albedo scenes. Initially, this data is radiometrically calibrated using calibration coefficients derived during ground testing of the instrument at Lincoln Laboratory. Next, regions of constant radiance are identified. The signal to noise ratio for each region is then calculated for each band. Table 3 lists the derived signal to noise ratios for all bands.

TABLE 3
SIGNAL TO NOISE RATIO FOR VARYING RADIANCES.

| Band | Radiance* | SNR | Radiance* | SNR | Radiance* | SNR |
|------|-----------|-----|-----------|------|-----------|------|
| 1p | 4.78 | 151 | 14.79 | 339 | 34.92 | 520 |
| 1 | 5.55 | 245 | 17.08 | 572 | 41.1 | 1263 |
| 2 | 5.11 | 310 | 16.10 | 1001 | 38.28 | 1536 |
| 3 | 4.29 | 343 | 13.37 | 1039 | 31.99 | 1933 |
| 4 | 3.34 | 358 | 10.44 | 722 | 25.03 | 1123 |
| 4p | 2.80 | 350 | 8.73 | 710 | 20.93 | 1145 |
| 5p | 1.40 | 263 | 4.42 | 662 | 10.66 | 1258 |
| 5 | 0.68 | 341 | 2.15 | 1040 | 5.13 | 1606 |
| 7 | 0.22 | 274 | 0.68 | 912 | 1.63 | 1636 |
| Pan | 4.82 | 215 | 15.04 | 348 | 36.01 | 703 |

* mW/cm² sr μ m

ONGOING WORK

The spatial resolution of the Advanced Land Imager is being quantified using observations of long bridges, dams, canals, and roads as well as observations of the Pleiades star cluster and the limb of the Earth's moon. This effort is ongoing and initial results from these studies are presented elsewhere in this conference [4].

The absolute radiometric accuracy of the Advanced Land Imager is currently under investigation. A significant problem with contamination build-up on the surface of the filters overlaying the focal plane was identified during the first 40 days on orbit. Since that time, the focal plane has been baked out for a period of twenty hours every seven days. These outgassing periods have been very successful and internal reference lamps, monitored daily, indicate any contaminant build-up between outgassing periods is effectively eliminated by warming the focal plane and the response of the instrument has been stable to within 2% for the ninety days since the outgassing cycle was adopted.

In addition to the monitoring of internal reference lamps, three other methods of confirming the absolute radiometric accuracy of the instrument have been adopted: ground truth observations, lunar observations, and solar observations. The ground truth observations consist of a series of field campaigns where absolute reflectance, atmospheric, and underflight measurements by ground teams or aircraft are performed while the EO-1 and Landsat 7 instruments image these regions simultaneously. At the writing of this paper, three campaigns have been conducted: Lake Frome Australia, Arizario Argentina, and Barreal Blanco Argentina.

Observations of the full Moon and observations of the Sun, using a novel technique, which allows the full dynamic range of the instrument to be calibrated during a single data collection period [3], have also been conducted.

Unfortunately, the data collected during ground campaigns, and observations of the Moon and Sun have only been recently acquired and radiometric results from these investigations are not mature enough to be presented at the time of this writing.

Additional information obtained prior to the IGARSS 2001 conference and not discussed here will be included in the oral presentation.

CONCLUSION

Initial results from the analysis of data collected by the Earth Observing-1 Advanced Land Imager indicate the instrument is healthy and functioning nominally. Focal plane saturation radiances, signal to noise ratios and sensitivities for all bands, which equal or better Landsat ETM+ specifications [5], have been provided. These results, along with others presented elsewhere [3,4] indicate an Advanced Land Imager type instrument would fulfill the requirements for a future Landsat mission.

REFERENCES

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